CHAPTER 8 - SAFETY

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CHAPTER 8 - SAFETY

8.1 GENERAL

The purpose of this chapter is to provide guidance for evaluating and developing highway safety alternatives to be incorporated into roadway and structural designs. This includes providing for the safe accommodation of traffic through construction work zones. The safety guidelines of any highway facility are primarily a reflection of the attitude of the administration responsible for the facility and the priority placed on the use of available funds. While the overall objective is maximum highway safety, environmental and economical restraints may prohibit achieving this goal. The designer must, therefore, ensure that the design provides the maximum safety enhancements for each dollar spent.

Agreements have been negotiated with most of the Federal agencies with significant public road mileage, and they have active programs to meet the applicable guidelines . In addition, the FLH Divisions provide technical guidance to many of these agencies in the design and construction of their road and works to assure that objectives of the Highway Safety guidelines are accomplished.

A. Safety Design Policy. New construction and reconstruction involves the application of appropriate guidelines in the design and construction of the facility. (See Chapter 9.) The application of those guidelines virtually ensures uniform geometrics and safety. Even with their use, however, operational or roadside safety problems may still exist that will not be identified unless a safety analysis is performed.

It is FLHO policy that RRR projects will be treated in a manner similar to new construction or reconstruction. Because of the limited scope of RRR projects, adoption of full guidelines may not be possible. When this occurs, the designer should identify the substandard features and analyze their potential effect on highway safety. The analysis and proposed mitigation are to be documented as discussed in Section 9.1.B of Chapter 9.

B. Roadway Safety. An accident is seldom the result of a single cause. Usually several influences affect the situation at any given time. These influences can be separated into three elements: the human, the vehicle, and the environment. The environmental element includes the roadway and its surroundings. The designer can only control roadway elements and must make judicious selection of the roadway geometrics, drainage, surface type, and other related items to lessen the potential for accidents and/or reduce the severity should they occur. The ideal design applies appropriate guidelines over a section of roadway.

The designer should avoid discontinuities such as the following in the highway environment:

- Abrupt changes in design speeds.
- Short transitions in roadway cross section.
- Short radius curve in a series of longer radius curves or at the end of a long tangent.
- Changes from full to partial access control.
- Roadway width constrictions such as narrow bridges or other structures.
- Intersections with inadequate sight distances.
- Hidden sag vertical curves and inadequate sight distance at crest vertical curves.
- Other inconsistencies in the roadway design.

Standardizing highway design features and traffic control devices reduces driver confusion and makes the task of driving easier. Through the use of these standard features, the driver learns what conditions to expect on a certain type of highway. The goal, if possible, is to design a highway so that a driver needs to make only one decision at a time. Multiple decisions confuse and distract a driver.

C. Roadside Safety. Roadside safety design has become increasingly important as new technology has made possible improvements in the alignment, grade, and roadway. When a vehicle leaves the roadway, any object in or near its path may become a contributing factor to the severity of the accident. The basic concept of a forgiving roadside is that of providing a clear recovery area where an errant vehicle can be redirected back to the roadway, stop safely, or slow enough to mitigate the effects of the accident.

Consult the *Green Book* and the *Roadside Design Guide* for guidance on appropriate clear recovery areas. The designer must evaluate these requirements in conjunction with environmental and economic constraints to determine the acceptable clear zone for the traffic, speed and terrain of the project.

Potentially hazardous features located within the identified clear zone should be treated as follows:

- Identify and remove the hazard.
- Relocate the hazard to a point where it is less likely to be struck, preferably outside the clear zone.
- When a potential hazard remains in the clear zone, make the hazard crash worthy.
- If the feature is potentially more hazardous than a barrier system that could shield it, consider installing the barrier system.

8.2 GUIDANCE AND REFERENCES.

The publications listed in this section provided much of the fundamental source information used in the development of this chapter. While this list is not all inclusive, the publications listed will provide a designer with additional information to supplement this manual.

Traffic Engineering Handbook. Institute of Transportation Engineers. 4th ed. 1991 .

A Guide to Standardized Highway Barrier Hardware. Task Force 13 Report, ARTBA. 1995.

Local Highway Safety Studies Users Guide. DOT, FHWA. Office of Highway Safety. July 1986.

Functional Requirements of Highway Safety Features. DOT, FHWA. 1981 edition with 1983 revisions.

Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD). DOT, FHWA. 1988 edition with approved revisions.

Synthesis of Safety Research Related to Traffic Control and Roadway Elements. DOT, FHWA. Volumes I and II. 1982.

Traffic Control Devices Handbook. DOT, FHWA. 1983.

Roadway Delineation Practices Handbook. DOT, FHWA. 1994

Selection and Design Criteria of Crash Cushions. DOT, FHWA. September 1975.

Identification of Hazardous Locations. Report No. FHWA RD-77-87. DOT, FHWA. 1977.

Highway Safety Engineering Studies - Procedure Guide. Report No. FHWA-TS-81-220. DOT, FHWA. 1981.

Traffic Control for Street and Highway Construction and Maintenance Operations Notebook. DOT, FHWA. 1985.

Alternate Approaches to Accident Costs Concepts. DOT, FHWA. 1984.

A Users Guide to Positive Guidance. DOT, FHWA. September 1990.

Sign Manual. Department of the Interior, National Park Service. January 1988.

Railroad-Highway Grade Crossing Handbook Users Guide. FHWA-TS-86-216. DOT, FWHA. 2nd ed. September 1986.

Designing Safer Roads. TRB Special Report 214. Transportation Research Board. 1987.

Analysis of Highway Accidents, Pedestrian Behavior, and Bicycle Program Implementation. Transportation Research Board. 1982.

Highway Capacity Manual. Special Report No. 209. Transportation Research Board. Third Edition 1994.

Operational Effects of Geometric and Improvement Evaluations. Transportation Research Board. 1981.

Recommended Procedures for the Safety Performance Evaluation of Highway Features. NCHRP Report No. 350. National Cooperative Highway Research Program. 1993.

8.2 Guidance and References. (continued)

Selection of Safe Roadside Cross Sections. NCHRP Report No. 158. National Cooperative Highway Research Program. 1975.

Highway Safety Design and Operations Guide. AASHTO. 1997

Glennon, J.C. *Roadside Safety Improvement Programs on Freeways* -- *A Cost Effectiveness Approach*. NCHRP Report 148. 1974.

8.3 INVESTIGATION PROCESS

The investigation process begins with the initial consideration and priority given to candidate projects for safety improvements. FLHP projects involve the preservation or improvement of the facility and the enhancement of roadway safety.

The majority of FLH projects involve existing roadways. On existing highways, historical information relating to the highway's operation or safety should be analyzed. The State Transportation Departments generally have operational and safety records for the Federal System. Respective agencies frequently have data for routes on their systems. Unfortunately, on off-system county roads, the available data may be scarce. This is often due to the low volume rural nature of the facility and many accidents on such facilities go unreported. Information retrieval systems may also be less developed for these roads. Good sources of information in such instances are law enforcement officials, local maintenance personnel, property owners, local businesses, mail carriers, school bus companies, etc. A drive through of the project, with a keen eye towards operational or safety problems or potential problems, will often detect areas requiring special attention during design.

A. Accident Data. Many State highway agencies maintain computerized accident files. They can provide statistics regarding statewide rates for fatal, injury, and property damage accidents as well as rates on specific routes. By comparing statistical trends in a given area of the State, the designer may detect clues to the basic causes or problems that should be addressed during design. For example, if a proposed FLHP project were located in a portion of a State that has higher than normal run-off-the-road accident rate, further analysis of the types of accidents (such as skidding) might be warranted.

The designer should review available accident reports to determine if any engineering features may have contributed to the problem. Law enforcement agencies can usually provide available accident reports. In the case of the National Park Service (NPS), each park maintains its own accident reports. In the past, the NPS used the same accident report forms for all accidents, and no attempt was made, until recently, to separate and file vehicle accident forms together. Recognition of this problem, however, has resulted in a service-wide effort to standardize the data input as well as to computerize it for easy retrieval. This effort, initiated in 1985, is known as the *Service-wide Traffic Accident Reporting System* (STARS). STARS will provide substantial information to the designer.

B. Traffic Safety Studies. Traffic safety studies, when available, provide excellent references for evaluating safety and operational characteristics. The NPS has had traffic safety studies performed in many of their larger parks. The States or other agencies may also have such information available on their systems. While the content and form of traffic safety studies vary widely, they usually include an introduction that describes the goals and purpose of the study and defines the study area and project specifics.

Physical and operational characteristics typically include

- functional classification,
- usage,
- traffic volumes,
- vehicle classification,
- inventories of roadway features,
- vehicle speeds,
- traffic conflict studies, and
- pedestrian/bicycle or rail conflicts.

Accident analysis typically provide location, type, rates, severities, and associated environmental factors. The report should be supplemented with appropriate photographs, maps, or detailed plan layouts. Generally, because of funding limitations, these analyses should address alternate safety improvements and include some method of assigning priorities to the recommended improvements.

Ranking is generally done by calculating a "hazard index" at specific sites. Detailed procedures for weighing the various causal factors and arriving at the "hazard index" are included in FHWA-RD-77-83, *Identification of Hazardous Locations*, and FHWA-TS-81-220, *Highway Safety Engineering Studies, Procedural Guide*. The hazard index and the relative cost factors are analyzed to rank improvement projects and provide the basis to make appropriate recommendations.

8.4 SAFETY ANALYSIS AND DESIGN

RRR construction projects shall meet guidelines that (1) preserve and extend the service life of highways, and (2) enhance highway safety. The extent of appropriate safety enhancements can be determined by performing a safety analysis. A safety analysis consists of analyzing potentially hazardous features and locations: both the project's accident history and the list of potentially hazardous locations and features should be used during the project development process. As a minimum, the designer should review this information on each project when a design exception is requested. The project files should contain documentation of the safety analysis performed and any improvements or mitigations taken to enhance safety.

A. Accident Analysis. The amount of data available for analysis will vary from project to project. Also, the level of detail and accuracy of the data may also vary. Therefore, the designer must determine on a case by case basis whether the data furnished for safety analysis purposes is satisfactory.

While not a normal function of the designer, accident lawsuits may indicate the need to evaluate accident reconstruction. This involves drawing inferences concerning the interactions of speed, position on the road, driver reaction, comprehension and obedience to traffic control devices, and evasive tactics. Accident reconstruction uses basic engineering knowledge of vehicle motion analysis, force analysis, and mechanical energy.

1. Accident History. The accident history for the project should be developed and analyzed to determine possible accident causes and to select appropriate safety enhancements. When practical, accidents should be summarized by location, type, severity, contributing circumstances, environmental conditions, and time period. This will help identify high accident locations and may indicate some spot safety deficiencies.

Depending on how accident information is filed, it may be necessary to record the information first and then group all accidents occurring at specific locations. This serves to identify high accident locations. Analysis of the types of accidents can suggest appropriate corrective action. The use of computer spread sheet programs will enhance the ability to evaluate this data.

Special consideration should be given to analyzing accident data on RRR projects. Limited accident data are common on rural two-lane highways with low to moderate traffic volumes. The limited amount of such data often makes traditional methods of analysis difficult.

Data generated from a small sampling can be misleading because they can be significantly influenced by small variances. Analysis of many RRR projects may require the following special efforts:

- A study of individual accident reports including those just beyond the project termini.

- A review to relate accident data with field conditions.

- Interviews with maintenance and/or police personnel. These interviews may reveal areas where operation problems or minor accidents occur but are not documented.

Accident analysis study procedures involve determining the significance of the accident history and developing summaries of the accident characteristics. The project's accident rates and summaries are used to detect abnormal accident trends or patterns and to distinguish between *correctable* and *non-correctable* accidents. Analysis of these summaries are used to identify possible safety deficiencies of the existing facility.

When summarizing accident data for analysis purposes, adhere to the following criteria:

- Select a time period for the collection of the accident data (such as 3 years). The time period chosen should contain reasonably current information on traffic volumes, pavement condition, and other site-related data. Past changes in the character of the facility (i.e., physical changes, roadside development, etc.) are accounted for when evaluating the accident activity.

- Examine accident data with respect to the direction the vehicles were traveling.

- Examine accident data with respect to location. Accidents occurring within an intersection area should be separated from those occurring outside the area of influence of the intersection. In addition, similar accident types occurring in differing situations should be recorded separately. For example, left-turn accidents into a driveway should not be included with left-turn accidents at an intersection. Collision diagrams may be useful in the analysis.

- Examine the number of accidents and the accident rates within the project termini. A comparison of this data with statewide norms for similar facilities should provide a reasonable indication of the relative safety of the existing roadway.

- Summarize the accident data and compare it to typical statistics on similar facilities. Patterns are categorized by a specific accident type. Following the identification of accident type patterns, the results are used to suggest possible causes of the accident patterns. Look at the severity patterns to determine if particular roadway or roadside features have contributed to the overall severity of the accidents that have occurred.

- Summarize the contributing circumstances portion of the accident report. This identifies possible accident causes noted by the investigating police officer. Contributing circumstances are categorized by (1) human (driver) factors, (2) vehicle related factors, and (3) environmental factors. The contributing circumstances information is used to verify, add, or delete possible causes developed by the accident summary by type procedure.

  The contributing circumstance data can be used to separate correctable and non-correctable accidents. In separating the accidents by these classifications, careful consideration should be made to ensure that the accidents are indeed non-correctable. Table 8-1 lists the contributing circumstances found on most accident reports and indicates if they are generally correctable or non-correctable through highway improvements.

- Summarize accidents by environmental conditions. This procedure identifies possible causes of safety deficiencies related to the existing condition of the roadway environment at the time of the accident. Typical classifications used in the analysis include lighting condition (i.e. daylight, dusk, dawn, dark) and roadway surface condition (i.e. dry, wet, snowy, icy, unknown).

These summaries are compared to average or expected values for similar locations or areas to determine whether the occurrence of a specific environmental characteristic is greater or less than the expected value at the location. For example, a higher than expected number of wet-surface accidents may be an indication of slippery pavement.

2. Probable Causes and Safety Enhancement. Probable accident causes need to be defined once the accident patterns are identified. On-site or photolog reviews of field conditions of accident sites are used to reduce the list of possible causes identified on the accident history to the most probable causes. The probable causes identified can then be used as a basis for selecting appropriate safety enhancements to alleviate the safety deficiency. Exhibit 8.1 is a listing of probable accident causes and possible safety enhancements. This list is not all inclusive; however, it does provide a general list of possible accident causes as a function of accident patterns and appropriate safety enhancements.

B. Potentially Hazardous Locations and Features. Hazardous locations or features on existing roadways may or may not be high accident locations. Many locations with narrow bridges, slippery pavement, rigid roadside obstacles, or other potentially hazardous conditions, have accident potential but may not yet have an accident history. Therefore, it is important to identify potentially hazardous locations or features in the development of projects. When accident history is not available, a project listing of potentially hazardous features and locations may be used to determine the need for safety enhancements. Exhibit 8.2 shows an example of a roadside hazard review.

Table 8-1
Contributing Circumstances

Driver-Related	
• Unsafe speed (C/N)	• Sick (N)
• Failed to yield right-of way (C/N)	• Fell asleep (C/N)
• Following too close (C/N)	• Lost (N) consciousness
• Improper passing (C)	• Driver inattention (C/N)
• Disregard traffic controls	• Distraction (C/N)
• Turning improperly (C/N)	• Physical disability (N)
• Alcohol involvement (C/N)	• Drug involvement (C/N)
Vehicle-Related	
• Brakes defective (C/N)	• Tow hitch defective (N)
• Headlights defective (C/N)	• Overload or improper loaded (N)
• Other lighting defects (C/N)	• Oversize load on vehicle (N)
• Steering failure (N)	• Tire failure/inadequate (C/N)
Environment-Related	
• Animal on roadway (C/N)	• Holes/deep ruts/bumps (C)
• Glare (C/N)	• Road under construction/maintenance (N)
• View obstructed/limited (C/N)	• Improperly parked vehicle(s) (C/N)
• Debris in roadway (N)	• Fixed object(s) (C)
• Improper/nonworking traffic controls (C/N)	• Slippery surface (C)
• Shoulders defective (C)	• Water ponding (C)
• Roadside hazards	
KEY: (C) = Correctable (N) = Non-correctable by safety enhancement (C/N) = Either correctable or non-correctable depending on related circumstances	

C. Alternative Evaluations. After the accumulation of available data, a roadside safety evaluation shall be performed. The results of the accident analysis and the list of potential roadside hazards provide the input for this evaluation. From these two sources, the designer should develop a composite list that locates and describes the identified safety problems.

Alternatives for correcting the safety problems should be developed and each evaluated for effectiveness, cost, and environmental impact. Alternatives may range from site specific improvements to total reconstruction. The evaluations, alternatives, and action selected should be documented in the project files.

D. Clear Zone. A clear zone (L_c) is defined as the roadside border areas (starting at the edge of the traveled way) that is available for safe use by errant vehicles. The width of the clear zone is influenced by the type and volume of traffic, speed, horizontal alignment, and side slopes. Slopes steeper than 1: 4 are not considered traversable by vehicles and the need for traffic barriers as discussed in Section 8.4.E should be evaluated. The AASHTO *Roadside Design Guide* also discusses clear zone widths.

Determine clear zone widths for all roadway tangent sections (except tangent sections on rural collectors and local roads and streets) by using Figure 8-1.

The AASHTO *Roadside Design Guide* and *Green Book* has additional guidance. Where feasible and environmentally acceptable, the clear zone width should be a minimum of 3 meters. On rural collectors and local roads and streets with a design speed of less than 60 km/h or an ADT less than 750, the clear zone width may be determined and documented on a project-by-project basis.

The clear zone on a curved alignment is determined by increasing the value obtained for a tangent section of highway. The tangent section clear zone is increased by a curve correction factor based on the degree of curvature, the design speed, and the roadside width. Clear zone widths for horizontal curves can be determined using Table 3.2 in the AASHTO *Roadside Design Guide* .

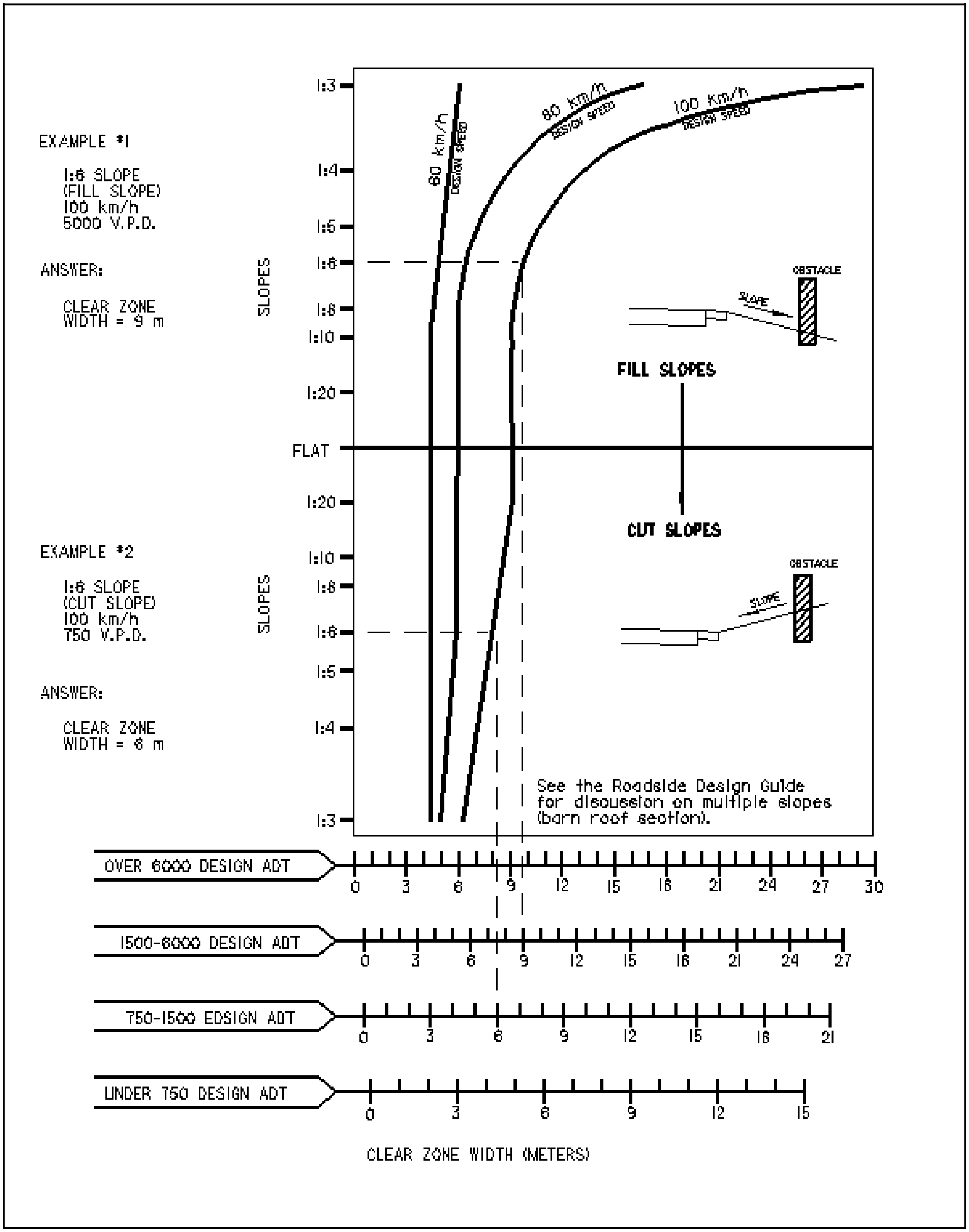

FIGURE 8-1
Clear Zone Distance Curves

E. Traffic Barriers. When clear zone requirements cannot be met, the designer should give special attention to the roadside hazards. Obstacles located within the clear zone should be *removed, relocated, or made breakaway*. If this is not feasible, then guardrail or some other type of roadside barrier should be considered, provided that the roadside barrier offers the least hazard potential.

1. Determining Needs. Roadside obstacles may be classified as non-traversable hazards or fixed objects.

The following are examples of non-traversable hazards that may warrant roadside barriers:

- Steep embankments (slopes steeper than 1:3).
- Rock cuts.
- Large boulders.
- Ditches.
- Culvert openings.
- Permanent bodies of water over 0.6 meters in depth.
- Large trees (over 100 mm diameter).
- Shoulder edge drop-offs steeper than 1:1 and depth greater than 0.6 meters.

A ditch section is safe or hazardous depending upon the type of sideslopes and widths. The *Roadside Design Guide* contains examples for a variety of ditch configurations. Frequently limited right-of-way, environmental factors and terrain will preclude the designer from being able to develop these preferred ditch sections. Preferred ditch sections should receive greater consideration on high speed, high volume facilities. Medians on divided roadways also deserve special attention.

The following are examples of fixed objects that may warrant roadside barriers:

- Bridge piers, abutments, parapets, or railings.
- Retaining walls.
- Fixed sign bridge and non-breakaway sign supports.
- Trees over 100 mm in diameter.
- Headwalls of box culverts or pipe culverts.
- Culvert end sections with diameters larger than 900 mm.
- Utility appurtenances.

The unprotected end of a bridge rail or parapet is considered a hazard. In most designs, an approach roadside barrier with a smooth transition to the bridge barrier is warranted. Exceptions to this policy may include structures designed for use on low volume, low speed highways. The *Roadside Design Guide* contains discussions for transition barriers.

Special attention needs to be given to the proper attachment of the transition railing with the bridge railing or parapet. The railing connection should develop the full tensile strength of the rail element and be designed to prevent possible pocketing or snagging of a vehicle on the end of the bridge parapet. The bridge plans should generally include special drawings of these connection details. Transition guardrail should satisfy the minimum *length of need* to develop its full tensile strength capacity. The terminal end should extend outside the lateral clear zone or be provided with a crash worthy terminal, protected by a crash cushion, or buried in a cut slope.

On many projects, existing bridges have inadequate bridge or transition railings. When replacing structurally obsolete bridges, railing replacement should meet current standards . When bridge railings are structurally adequate but functionally obsolete, engineering analysis should be performed to determine the recommended action on a case-by-case basis.

Accidents involving roadside hazards represent a problem inherent to any existing highway facility. Even on new or reconstructed projects, the complete elimination of all roadside hazards may not be feasible or practical. See Section 8.1.C for a priority list when evaluating roadside hazards.

Appendix A of the *Roadside Design Guide* provides a cost effective selection procedure for comparing alternative solutions to problem locations and instructions for operating the *ROADSIDE* computer program. The annual cost of each alternative is computed over a given period of time, taking into consideration initial costs, maintenance costs, accident costs, and salvage value. Accident costs incurred by the motorist, including vehicle damage and personal injury, are considered together with accident costs incurred by the highway department or agency. The alternative with the least total cost is normally selected, except when environmental or aesthetic considerations dictate otherwise.

When determining the need for traffic barriers, consider cost when evaluating the following four alternatives:

1. Remove or reduce hazard so that shielding is unnecessary.

2. Install a barrier.

3. Leave hazard unshielded but sign or delineate.

4. Do nothing.

The third option is normally cost effective on low volume and/or low speed facilities, or where the probability of accidents is low.

With regard to installing a barrier, the procedure allows the designer to evaluate any number of barriers that can be used to shield the hazard. Through this method the following can be evaluated: the effects of average daily traffic, offset of barrier or hazard, size of barrier or hazard, and the relative severity of the barrier or the hazard.

The ability to easily vary input data allows the designer to explore various areas of sensitivity of the analysis at a given location. The effects of current traffic and future traffic can be explored to evaluate cost effectiveness over the design life of a project. Although most of the data collected through research pertains to high speed situations, the designer can analyze how sensitive the cost effectiveness is with respect to the severity index. However, a correlation can be made provided the designer recognizes that lower design/running speeds would lessen severity. Use of this tool has been successful in persuading reluctant agencies to recognize the cost effectiveness of selected safety feature applications.

These programs access research information by Kennedy-Hutcheson for high-volume roads and Glennon for low-volume roads with roadway widths less than 8.5 meters. The program shows both *annual cost* comparison and *present worth*. Generally the *annual cost* is used to facilitate comparison of different alternatives with varying design life.

For low-volume, low-speed roads, strict adherence to the guardrail warrants shown in the *Roadside Design Guide* is frequently not practical or cost effective. The NPS and the FHWA have jointly developed *Park Road Standards*, published by NPS in 1984. A draft metric update was distributed for use on September 2, 1997, but NPS has not republished the metric version. Although developed specifically for NPS roads, the basic principles in these guidelines are applicable to other types of low- volume, low-speed roads.

The *Park Road Standards* states:

> *Guardrail or guardwall should be installed at points of unusual danger such as sharp curves and steep embankments, particularly at those points that are unusual compared with the overall characteristics of the road.*

Similar wording is used in the AASHTO *Green Book* in the section that deals with recreational roads.

Although the *Guides* are still used as a basis for determining need for barriers on recreational roads, they are not always applicable to these roads. Besides low speeds and low volumes, NPS roads frequently have other characteristics that affect barrier needs.

These include the following:

- Roads closed in winter and during periods of hazardous climatic conditions.
- Roads closed at dark.
- Roads with access limited to passenger- carrying vehicles.

Another consideration affecting the use of barriers is for areas having unusual environmental sensitivity including endangered plants and animals as well as major historic and scenic resources.

The *unusual danger* noted in the NPS standard, when compared with the rest of the roadway, has been reduced to the following criteria for roads that have continuous sharp curves and steep slopes throughout much of their lengths:

- Consider barriers in areas with high embankments and slopes steeper than 1:2 and where rock embankments and retaining walls prevent the growth of vegetation.
- Consider barriers in areas with steep slopes or other roadside hazards where unusual conditions exist that may surprise or distract the motorist. For example, sharp curves at the end of long tangents (especially on downgrades) or approaches to scenic vistas at sharp curves.
- Consider barriers at locations with accident histories, where the accident severity could have been reduced with a barrier.

Always remember that a barrier is itself a significant hazard and is more likely to be hit than the hazard that it is to protect. Therefore, the relative severity, costs, and frequency of accidents must be considered.

Although the warrants cover a wide range of roadside conditions, special cases or conditions will arise for which there is no clear choice. Such cases must be evaluated on an individual basis, and, in the final analysis, must usually be solved by engineering judgment.

2. Type Selection. Once it has been determined that a barrier is needed, type selection will be made. While the most predominant type of roadside barrier used on Federal Lands projects is metal W-beam guardrail, the designer needs to be cognizant of various selection criteria for roadside barriers. Table 8-4 lists the various criteria that should be considered.

The designer is again referred to the *Roadside Design Guide* for design criteria of the various systems. As indicated in the *Roadside Design Guide*, barrier systems are classified as either operational, experimental, or Research and Developmental (R&D). The standard drawings for W-beam guardrail mounted on wood or metal posts are examples of approved operational guardrail systems.

Crash tests performed for FLHO using NCHRP 230 and 350 criteria to evaluate aesthetic barrier systems indicated acceptable crash test results. Use of these systems are classified as operational. For design and construction notes for these systems see Exhibit 8.3.

Research efforts are in progress to identify and crash test other systems for possible use on FLHP projects.

The owner agency generally selects the type of roadside barrier. It is the designer's responsibility to ensure that the selected barrier has been tested and approved for use and designed to function where installed.

The FHWA final rule, published in the Federal Register on July 16, 1993, required that roadside safety hardware installed on the National Highway System (NHS) routes must meet the requirements of National Cooperative Highway Research Report 350 (NCHRP 350). The dates the rule becomes effective depends upon the type of hardware. The effective date for roadside barrier systems and terminals is October 1998. The effective date for bridge to barrier transitions is October 2002.

The FLH policy requiring barriers systems to meet the requirements of NCHRP 350 is provided below:

Routes on the NHS.

> State and local routes: As required by FHWA, it is the policy of the FLH to use only roadside safety hardware that meets NCHRP 350 criteria. No exceptions are permitted, except for specific hardware items receiving delays or temporary waivers granted by the FHWA, Office of Engineering (HNG-14).
>
> National Park Service (NPS) routes: It is also the policy of the FLH that all roadside safety hardware shall meet NCHRP 350 criteria on NPS routes. All new aesthetic roadside barrier systems shall be tested under NCHRP 350 criteria.
>
> A request for acceptance of aesthetic barrier systems previously accepted under NCHRP 230 may be submitted to the Office of Engineering for consideration . The Office of Engineering may determine that the barrier is acceptable under NCHRP 350 criteria without retesting, if the test result data under NCHRP 230, or results from similar systems tested under NCHRP 350, indicate the system is likely to meet NCHRP 350 criteria.

Routes not on the NHS . The FLH shall comply with the owning agencies' policies on roadside safety hardware on non-NHS routes. The owning agencies' policies will be referenced as the reasons for permitting barrier systems that do not meet NCHRP 350 criteria. However, no barrier systems shall be used that have not passed NCHRP 230 criteria. If the agencies have no policy, FLH shall specify roadside safety hardware that meets NCHRP 350 criteria. (Although there is no regulatory requirement, the FHWA strongly encourages safety hardware used on non-NHS routes to meet NCHRP 350 criteria).

> <u>State and local routes</u>: Due to issues such as maintenance of barrier systems, state or local agencies may require barrier systems that do not meet NCHRP 350 criteria. The FLH Divisions shall insure the owning agencies are aware that proposed systems do not meet NCHRP 350 criteria before complying with the owning agencies' requests. The FLH Divisions should document reasons for specifying barrier systems that do not meet NCHRP 350 criteria.
>
> <u>NPS routes</u>: All barrier systems shall meet at least NCHRP 230 criteria. All new barrier systems shall be tested under NCHRP 350 criteria. Currently none of the aesthetic roadside barrier systems approved under NCHRP 230 have been retested to NCHRP 350 criteria. FLHO and NPS will decide whether to retest individual barrier systems. The decision to use barrier systems that do not meet NCHRP 350 criteria should be documented.

Roadside safety hardware meeting NCHRP 350 criteria are currently being accepted by the Office of Engineering following a review of data submitted by the vendor or the developer of the system. Updated lists of approved barrier systems may be found on the FHWA Web page (the URL address is http://www/fhwa.dot.gov/engineering/HNG10/ROADSIDE.html). If no acceptable non-priority barrier terminal systems and transitions are available that meet the project needs, at least three acceptable proprietary systems (if available) shall be permitted as options in the contract.

Test level warrants are being developed under an NCHRP study, but have not yet been published. Until warrants are available, the test levels (defined in Table 3.1 of NCHRP 350) as noted in Table 8-3, have been determined to be appropriate for National Park Service park roads and parkways. Barriers should be tested to the level of expected highest use.

Table 8-2
Test Level Matrix

Interim Test Levels For NPS Park Roads and Parkways		
SPEED (V) (km/h)	SEASONAL ADT	TEST LEVEL (test V)
$V \leq 50$	-	1 (50)
$50 \leq V \leq 70$	$\leq$ 20 000	1 (50)
$50 \leq V \leq 70$	$\geq$20 000	2 (70)
$70 \leq V \leq 100$	$\leq$ 20 000	2 (70)
$70 \leq V \leq 100$	$\geq$20 000	3 (100)
$V > 100$	-	3 (100)

.

Table 8-3
Selection Criteria for Roadside Barriers

Characteristic	Considerations
Deflection	Space available behind barrier must be adequate to permit dynamic deflection of barriers.
Strength and Safety	System should contain and redirect vehicle at design conditions. System should be as safe as possible considering costs and other considerations.
Maintenance	Collision maintenance. Routine maintenance. Environmental conditions. Inventory of spare parts.
Compatibility	Can system be transitioned to other barriers? Can system be terminated properly?
Costs	Initial costs. Maintenance costs. Accident cost to motorist.
Field experience	Documented evidence of barrier's performance in the field.
Aesthetics	Barrier should have a pleasing appearance.
Promising new designs	It may be desirable to install new systems on an experimental basis.

3. Design Procedures. Once the need for barrier has been determined, the designer must determine the length and location for the barrier. The following discussion outlines the significant elements for locating and designing roadside barriers. However, the designer must refer to the *Roadside Design Guide* for specific details and limiting criteria for layout and use of the barrier selected.

a. Length of Barrier. The length of need is equal to the length of the area of concern parallel to the roadway, plus the length of the approach barrier on the upstream side (and downstream side if needed), plus a safety end treatment.

Where slopes outside of the graded shoulder are flat enough, the barrier approach should be flared or the guardrail installation located outside of the graded shoulder to minimize the length of need. More commonly, where slopes are steeper, the barrier will run along the shoulder. Figures 8-2 and 8-3 depict both cases. The minimum barrier lengths in advance of hazardous area shown are adequate for most installations. Where greater lengths of need are desired, the formulas shown in Figure 8-3 may be used or a sketch of the location may be drawn to scale and the length of need measured.

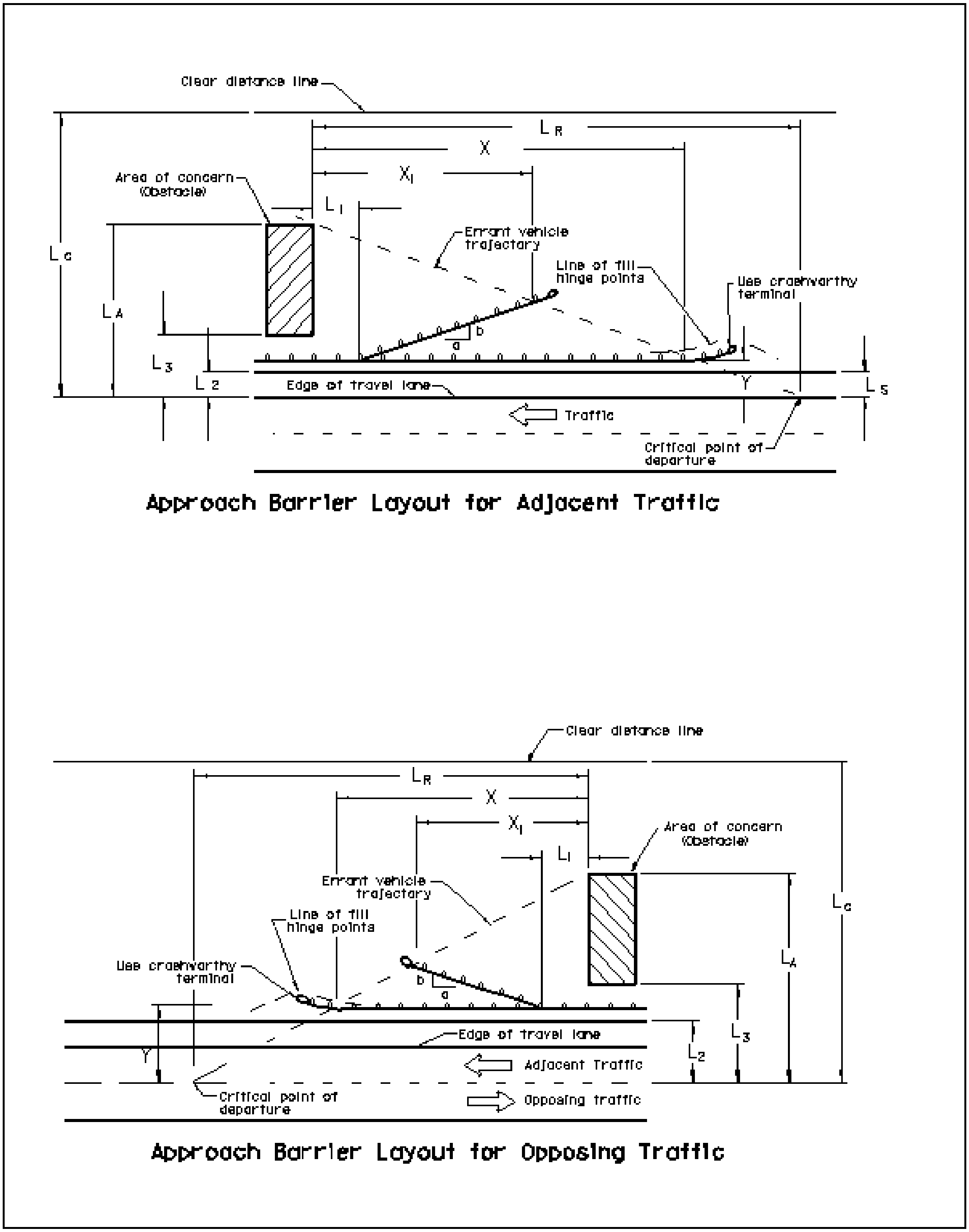

Figure 8-2
Guardrail Length Requirements

Operating Speed (km/h)	Shy Line Offset L_s (m)	Runout Length L_R (m)				Flare Rate a:b		
		Over 6000 ADT	2000-6000 ADT	800-2000 ADT	Under 800 ADT	Inside Shy	Rigid	Yielding
110	2.8	145	135	120	110	30:1	20:1	15:1
100	2.4	130	120	105	100	26:1	18:1	14:1
90	2.2	110	105	95	85	24:1	16:1	12:1
80	2.0	100	80	80	75	21:1	14:1	11:1
70	1.7	80	75	65	60	18:1	12:1	10:1
60	1.4	70	60	55	50	16:1	10:1	8:1
50	1.1	50	50	45	40	13:1	8:1	7:1

Flared Approach:

$$X_1 = \frac{L_A + \left(\frac{a}{b}\right) L_1 - L_2}{\left(\frac{a}{b}\right) + \left(\frac{L_A}{L_R}\right)}$$

Standard Approach:

$$X = L_R\left(\frac{L_A - Y}{L_A}\right)$$

Where:

The distance X or X_1 is the minimum length of need.

L_A= Distance (m) from the edge of the traffic lane to the back of the hazard or clear zone line whichever is less

Y = Distance (m) from the edge of traffic lane to the end of the barrier need

L_C= Clear zone (m)

Figure 8-3
Guardrail Length Requirements

b. Barrier Located Adjacent to the Graded Shoulder. Designers should be aware that barrier installations require widening of the shoulder to provide adequate soil support. In addition, special attention is required at barrier terminals to ensure that widened areas are graded correctly so that the terminal will function properly.

c. Barrier Located Back of the Graded Shoulder. When barriers are located in back of the graded shoulder or when barriers are flared back of the shoulder edge, slopes in front of the barrier shall be 1:10 or flatter. Also, the algebraic difference between the shoulder slope and the slope in front of the guardrail should not be greater than 8 percent. The two exceptions to this requirement are as follows:

- Barrier may be located on slopes 1:6 or flatter, provided the shoulder is adequately rounded and the barrier is placed more than 3.7 m from the edge of the graded shoulder.

- Where shop curved sections of barrier are used with buried terminals, a portion of the shop curved section (not more than 1 m in length) may extend back of the graded shoulder onto normal slopes.

d. Barrier/Curb Combinations.

- All Barrier/Curb Combinations: Concrete curb and gutter, header curb, or other rigid type curb used in combination with barrier should be avoided whenever possible. Curb should not be used in front of barrier unless the combination has been successfully crash-tested.

- Guardrail/Curb Combinations: Where there are no other feasible alternatives to guardrail/curb combinations, the face of curb should be located behind or flush with the face of guardrail. However, crash tests have shown some guardrail/curb combinations with curb located flush with the face of the guardrail can cause vaulting due to deflection of the rail. Therefore, curb higher than 100 mm should not be used with guardrail unless: 1) the guardrail/curb combination has been successfully crash-tested; or 2) the rail is adequately reinforced (stiffened) to reduce its deflection. On lower speed roads, use of a reinforced rail may not be cost-effective. Such locations are best analyzed on a case-by-case basis, taking actual or anticipated operating speeds into account and considering the consequences of vehicular penetration.

Chapter 3 of the *Roadside Design Guide* contains additional information on curb and barrier/curb combinations.

F. Crash Cushions. Crash cushions shield errant vehicles from impacting fixed rigid hazards (e.g., intersection of bridge parapets at a gore area) by smoothly decelerating the vehicle to a stop condition when hit head on. Also, it is desirable for the crash cushion to redirect a vehicle when hit from the side by functioning in a manner similar to a longitudinal barrier.

1. Determination of Need. As with longitudinal barriers, the first consideration with regard to a rigid object or hazardous conditions is to evaluate the feasibility of removing the obstruction, relocating it, or making it breakaway. When these options are not feasible, the next step is to determine whether or not some type of barrier is warranted by analyzing the cost effectiveness as described in Section 8.4.C. The cost-effective procedure can be used to evaluate both longitudinal barriers as well as crash cushions. Before the development of crash cushions, many fixed object hazards could not be effectively shielded at all; therefore where appropriate, crash cushions may prove to be very helpful.

2. Types of Crash Cushions. The *Roadside Design Guide* lists operational types of crash cushions. The best reference source available to the designer is FHWA's *Selection and Design Criteria of Crash Cushions*. Updated lists of approved crash cushions may be found on the FHWA Web page. As with barriers, crash test criteria can be found in NCHRP Report 350.

3. Design Procedures. The State of the Art regarding crash cushions is rapidly changing as new products are developed and tested. The most recent manufacturers' literature should be referred to when incorporating crash cushions into a design.

FHWA periodically issues clarifying instructions regarding the use or design of various systems as modifications are made or as additional crash test data becomes available.

While the use of crash cushions on FLH projects is expected to be quite limited, the designer should realize that rapid development in this area is taking place. Where use of a crash cushion is warranted, the designer should ensure that the most recent design criteria is used.

G. Signing and Delineation. Communication with the motorist is one of the most complex problems of the design engineer. One of the best communication tools available is the *MUTCD*, which depicts the national standards developed for all signing, signalization, channelization, and pavement markings for all highways in the United States. The FHWA *Standard Highway Sign Book* and the NPS *Sign Manual* both provide design criteria, methods, and charts for design.

All traffic control devices shall be in accordance with the *MUTCD*. Compliance with the requirements of the *MUTCD* for all traffic control devices is mandatory and includes the following:

- Use
- Placement
- Uniformity
- Maintenance
- Color
- Size
- Shape
- Legend
- Reflectivity
- Removal when not applicable

The main message of the *MUTCD* is the importance of uniformity. Substantial adherence to this manual is required on all public roads. However, some owner agencies have supplements to it or have developed similar manuals, such as the NPS *Sign Manual*, that must also be considered when designing and constructing roads under NPS jurisdiction. The *Traffic Control Devices Handbook* provides a compendium of traffic control system technology.

Highway users are dependent on traffic-control devices (signs, markings, and signals) for information, warning, and guidance. Uniform high-quality devices are important for the safe, efficient use and public acceptance of any highway regardless of the roadways excellence in width, alignment, and structural design.

Any traffic control device should do all the following:

- Fulfill an important need
- Command attention
- Convey a clear, simple meaning
- Command respect of road users
- Give adequate time for response

It should be noted that devices controlling or regulating traffic must be sanctioned by law.

Four basic principles are used to ensure that these requirements are met:

- Design
- Placement
- Maintenance
- Uniformity

Consideration shall be given to these principles during the design stage to ensure that the required number of devices can be minimized and properly placed.

1. Signing. The above cited references provide the designer with the information required to properly select the appropriate signing. Sign supports should be designed in accordance with the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaries, and Traffic Signals*. Owner agency practice, in accordance with the above standards, may dictate the types of materials to be used. Sign supports and luminaries located within the clear zone should be either crash worthy or made breakaway.

Designers should be aware that the NPS-52 *Traffic Control Guideline* requires each park to have an established sign plan. These plans should be reviewed together with accident statistics and any available safety studies to ensure continued appropriateness whenever additional construction work takes place. Similar plans may exist on specific routes with other owner agencies and should likewise be requested and reviewed.

The authority for regulatory signing rests with the maintaining/regulating agency. Likewise, the client agency may have specific concerns regarding warning or informational signs. The designer's responsibility is to identify all signs required and review them with the appropriate agencies during project development.

2. Pavement Markings. Pavement markings have definite and important functions to perform in a proper scheme of traffic control. In some cases, they are used to supplement the regulations or warnings of other devices such as traffic signs or signals. In other instances, they are used alone and produce results that cannot be obtained by the use of any other device. In such cases they serve as a very effective means of conveying certain regulations and warnings that could not otherwise be made clearly understandable.

Pavement markings have definite limitations. They can be obliterated by snow, may not be clearly visible when wet, and may not be very durable when subjected to heavy traffic. ln spite of these limitations, they have the advantage, under favorable conditions, of conveying warnings or information to the driver without diverting the driver's attention from the roadway.

a. General Application. Each standard marking shall be used only to convey the meaning prescribed for it in the *MUTCD*. Before any new paved highway, surfaced detour or temporary route is opened to traffic, all necessary markings shall be in place.

Remove or obliterate markings no longer applicable and which may create confusion in the mind of the motorist as soon as practicable. Painting out markings is not an acceptable method of obliteration. Markings which must be visible at night shall be reflectorized unless specific external illumination is provided.

All two-way paved roads, 5.5 meters or more in width, shall have centerline stripes. All multilane highways shall have lane line markings. Edge lines shall be provided on all rural multi-lane divided highways. Edge lines should be provided on all highways as follows:

- When the traffic exceeds 2000 ADT.
- In areas of frequent inclement weather and/or reduced visibility.
- In mountainous terrain where increased delineation is desirable.

All markings shall be placed in accordance with the *MUTCD.*

b. Pavement Marking Materials. The standard material to be used for pavement markings is an applied paint with reflective beads. All other pavement marking materials are considered to be upgraded materials. To upgrade, consideration shall be given to material performance, material cost, traffic volume and type, climatic conditions, and availability of materials and installation equipment (both for initial installation and maintenance). Only when an upgraded material is established to be more cost effective than the standard material, can the upgraded material be used. The following guidelines may be used for upgrading the striping material in lieu of an economic evaluation:

(1) Epoxy thermoplastic (ETP), epoxy, and polyester materials may be specified for centerlines, lane lines, and edge lines under any of following conditions:

- The ADT is in excess of 1000 vehicles per lane.
- Because of environmental, traffic, or climatic conditions, it is necessary to restripe with paint two or more times a year.
- The location is not proposed or scheduled for sealing or resurfacing within the next 3 years.

(2) Additionally, thermoplastic and preformed plastic type materials may be allowed for centerlines, lane lines, and edge lines when both of the following conditions are met:

- The ADT is in excess of 5000 vehicles per lane.
- The location is not proposed or scheduled for sealing or resurfacing within the next 5 years.

Epoxy thermoplastic, epoxy, or polyester materials may be specified under lower traffic conditions where there is a need to emphasis transitions, channelization, or special markings such as stop lines and crosswalks. These materials should not be specified under the lower traffic condition if it is less than 3 years before the pavement is scheduled for sealing or resurfacing.

(3) The appropriate type of raised pavement markings and/or snow plowable recessed low profile markers should be considered for the following:

- Intersection channelization.
- Directional left turn lanes.
- High hazard/accident locations.
- Areas of frequent inclement weather.
- Combined installations with preformed plastic markings where no overhead lighting exists.
- Gore areas and approaches to deceleration lanes.

Pavement striping tape may be specified as a temporary measure when conditions do not permit painting or while the highway is under construction.

H. Traffic Control. The safe and efficient movement of traffic through the highway project necessitates that designers review the proposed design from a traffic operations standpoint. The designer needs to be alert for situations that involve alterations in the driver's behavior or changes in driver attention. During the design phase, make an attempt to perceive the final roadway as it will appear to the motorist to anticipate the necessary traffic control devices needed to provide the user with sufficient advance information so the highway can be driven safely. Through the proper application of design standards, the number of motorist decision points will be minimized. There will, however, always be a need for appropriate permanent traffic control devices to inform, regulate, and/or warn the motorist. A review of the safety analysis will generally identify areas of existing operational problems.

Field reviews during construction are encouraged to substantiate if the original perceived operational characteristics of the project were germane and to provide timely adjustments during construction should they be warranted. After construction is completed and the project opened to traffic, an evaluation should be made of the traffic control devices to determine their adequacy and if they are functioning as planned.

1. Traffic Control Through Construction. Construction activity presents many traffic control problems that must be addressed by the designer. Regardless of whether the project is open or closed to public traffic, some form of construction traffic control will be required. A plan directed to the safe and expeditious movement of traffic through construction and to the safety of the work force performing those operations is defined as a Traffic Control Plan (TCP).

It is FLHO policy that a TCP be designed and incorporated into all projects.

2. Traffic Control Plan (TCP) Development. The purpose of the TCP is to anticipate and describe those traffic control measures that will be necessary during project construction and to outline coordination needs with owner agencies and the public.

Traffic control plans will vary in scope and complexity depending upon the type and volume of traffic and the nature of the construction project. At an early stage in the project development, the development of the TCP should begin and a determination made of the nature and volume of current and predicted traffic. All interested agencies should be involved throughout the development of the TCP. For projects with low-traffic volumes or that otherwise have few traffic hazards or conflicts, the TCP may be quite simple.

For projects that have one or more of the following characteristics, the TCP will normally be more complex:

- High volume or high speed traffic.
- Rush hour or seasonal traffic patterns.
- Heavy use by pedestrians.
- Changing work conditions or other conditions that would be confusing to the traveling public.
- Hazards due to nighttime operations.
- Complex detours or traffic patterns.
- Closely spaced intersections, interchanges, or other decision points.

In developing the TCP, consider the following items as appropriate. (These items may be used as a checklist in either developing or reviewing the adequacy of traffic control plans.)

- Estimated traffic volumes, vehicle types, and direction of travel.
- Traffic speeds.
- Required number of travel lanes.
- Traffic control layouts including signing, markings, channelization devices, traffic signals, traffic delineators, barriers, and detour schemes.
- Restrictions on work periods such as rush hours, holidays, special events, nights, weekends.
- Characteristics of adjacent highway segments.
- Requirements for partial completion and opening sections to traffic.
- Maneuvering space available for traffic.
- Requirements for installing, maintaining, moving, or removing traffic control devices.
- Turns or cross movements required by traffic.

- Restrictions on contractor hauling or moving materials.
- Provisions for accommodating adjacent businesses or residential areas.
- Provisions for accommodating emergency vehicles such as ambulance, fire, and police.
- Any special requirements for the contractor's traffic safety coordinator.
- Requirements for after hours surveillance or on-call personnel.
- Special requirements for nighttime operations.
- Restrictions on parking vehicles, storing materials, and the contractor's equipment.
- Special provisions for pedestrian movements.
- Provisions for accommodating regularly scheduled services such as postal vehicles and school buses.

All TCP features, which are obligations on the part of the contractor, shall be included in the plans and specifications. When necessary, appropriate standard typical traffic schemes shall be included in the plans.

The *MUTCD* shall be used as a standard for signs, striping, and other traffic control devices. Because of the general nature of the *MUTCD,* it will usually be necessary to use supplemental information.

The contract PS&E shall include the minimum requirements for controlling traffic through the construction work zones. However, the contractor may furnish alternate or additional means for accommodating traffic, subject to approval of the engineer.

Include traffic control provisions in the PS&E distribution made to other offices and agencies for review before advertising in order that these other parties may have an opportunity to review the provisions for adequacy and coordination.

Payment for TCP activities will usually be made by individual bid items for services, traffic control devices, signing, etc. For projects with only light traffic where traffic control procedures are minimal, payment may be incidental to other items of work or paid for on a lump sum basis.

There may be certain traffic control information that is of value to the project engineer but should not be included in the contract. In this case, such information should be documented and copies provided to the appropriate Construction units. This information may include the following:

- The need for public relations, such as notifications to the local news media.
- Any special agreements reached with other agencies relating to traffic control or traffic management.
- Accident reporting requirements.
- Any special guidance on traffic management for the project engineer.

The TCP as contained in the contract must be adopted by the contractor unless an alternate TCP is developed by the contractor and approved by the engineer prior to beginning construction operations.

3. Temporary Pavement Markings. The TCP should reflect FLH policy that pavement markings conforming to full MUTCD standards (Sections 3A and 3B) shall be installed as quickly as practical in the construction process. Special standards described below are available to accommodate the periods of time before installation of permanent markings is practical. These standards are consistent with the 1988 Edition of the MUTCD, Revision 3, dated September 3, 1993.

a. Definitions.

■ Temporary Pavement Markings - Either interim or standard markings installed prior to the installation of permanent markings.

■ Interim Markings - Interim markings are special, reduced dimension, temporary centerline, and lane line markings which are permitted by MUTCD Subsection 6F-6b. on new pavement lifts unless additional pavement lifts or standard markings are installed within specific time frames. Interim markings must conform to the color and retroreflection requirements of MUTCD Sections 3A and 3B.

■ Standard Markings - Standard markings are centerline, lane line, and no-passing zone markings which comply fully with the dimensional, color and retroreflection requirements of MUTCD Sections 3A and 3B. Standard markings may be either temporary or permanent, although permanent markings typically have additional contractual requirements.

■ Vehicle Positioning Guides - Temporary raised pavement markers, installed on centerline and lane lines immediately after paving but prior to the installation of temporary or permanent pavement markings. See MUTCD Section 3B-14.

■ Severe Curvature - Roads with a design speed of 55 km/h or less, or curves with design speeds of at least 15 km/h less than the design speed for the remainder of the road.

b. Unmarked Pavement. The MUTCD permits a limited period of unmarked pavement upon opening to traffic and prior to the required installation of temporary or permanent markings. During this period, it is important that adequate delineation and signing be provided as follows:

■ Vehicle positioning guides shall be installed on centerline and lane lines at a maximum spacing of N (N= cycle length, usually 12 meters) in combination with appropriate signs, channelizing devices and other delineation. Spacing should be reduced to 0.5 N in severe curvature situations.

■ A warning sign, "Unmarked Pavement" shall be placed at the beginning of each unmarked section, and after each major intersection or entrance ramp.

■ If sections of severe curvature or restricted visibility dominate the construction area, such that passing zones are inappropriate throughout the project, standard advance warning signing at the beginning of the project shall include "No Passing Next ____ Miles". In addition an R 4-1 "Do Not Pass" sign shall be installed at the beginning of the project and approximately every kilometer thereafter.

■ If each no-passing zone is to be signed separately, an R 4-1 "Do Not Pass" sign shall be used at the beginning of each zone, and repeated at maximum one-kilometer intervals if necessary. At the end of each zone an R 4-2 "Pass With Care" sign shall be used. On other than low volume roads, and when special hazards are present, the R 4-1 sign at the beginning of each zone should be supplemented by a W 14-3 "No Passing Zone" sign.

c. Marked Pavement. Temporary markings shall be required if the time limitations as described below for Unmarked Pavement, are exceeded and it remains impractical to install permanent markings. Temporary markings should be standard markings, unless the specific time limitations of interim markings can be met. The following are special standards for interim markings:

■ Centerlines and Lane Lines - MUTCD Section 6F-6b(1). and the Standard Specifications require interim broken-line pavement markings to be 1-meter stripes on 12-meter cycles (11-meter gaps), or 0.5-meter stripes on 6-meter cycles in severe curves. When 30 percent or more of the road is designated as meeting the criterion for severe curvature, the entire road may be striped on a 6-meter cycle. Temporary raised pavement markers may be substituted for broken line segments as permitted by the Standard Specifications.

■ No Passing Zone Lines - MUTCD does not recognize a special standard for interim no-passing zone lines. Whenever interim centerline markings are used, standard no passing zone lines shall be used, and shall meet the dimensional requirements of MUTCD Section 3A and 3B. Temporary, raised pavement markers spaced at 1.5 meters may be substituted for a solid line except during extended delays (six weeks or more) and winter shutdowns.

■ Edge Lines - Temporary edge lines are not required, except that if there is a winter shutdown or extended delay (of 6 weeks or more) in the completion of paving and installation of permanent markings, temporary edge lines meeting the requirements of Sections 3A and 3B shall be installed on those roads where edge lines were present prior to construction, and permanent edge lines are specified in the contract.

d. Time Limitations - Low Volume Roads [ADT ≤ 1000] . When average daily traffic does not exceed 1000 vehicles per day, and when the installation of permanent markings is not practical or possible immediately prior to opening the road to traffic, the use of the following standards are applicable.

■ For a scheduled duration of not more than two weeks after opening of a new lift of pavement, the minimum requirements of 8.4.3.b. Unmarked Pavement, above shall apply.

■ As an option to unmarked pavement during the same two week time frame, temporary centerline markings meeting the standards of interim markings as defined in 8.4.3.c. Marked Pavement above are permitted.

■ For scheduled duration of more than two weeks after opening of a new lift of pavement, the minimum requirements of standard markings as defined in 8.4.3.a. shall apply; as well as the requirements for edge lines in 8.4.3.c. Marked Pavement.

e. Time Limitations - Other Than Low Volume Roads [ADT > 1000]. When average daily traffic exceeds 1000 vehicles per day, and when the installation of permanent pavement markings is not practically possible immediately prior to opening the road to traffic, the use of the following standards are applicable.

■ For a scheduled duration of not more than three days after opening of a new lift of pavement, the minimum requirements of 8.4.3.b. Unmarked Pavement, above shall apply.

■ For a scheduled duration of not more than two weeks after opening of a new lift of pavement, the minimum requirements of interim markings as defined above in 8.4.3.c. Marked Pavement shall apply.

■ For scheduled duration of more than two weeks after opening of a new lift of pavement, the minimum requirements of standard markings as defined in 8.4.3.a., as well as the requirements for edge lines in 8.4.3.c. Marked Pavement shall apply.

f. Contract Items. Contract requirements and contract items should be structured so as assure safety while not subsidizing or encouraging delays, inefficiencies and excessive use of temporary markings and related traffic control.

■ Vehicle Positioning Guides are not considered centerline markings, but may be paid for as Temporary Raised Pavement Markers, or considered a subsidiary obligation. Additional signing and/or channelization devices necessary during periods of unmarked pavement should be anticipated and included in TCP's. (See Standard Drawing M635-01).

■ Generally the use of a contract item for temporary pavement markings is discouraged, especially on low-volume roads, unless it is determined that the installation of permanent markings within the available time limitations is not practical or possible. If permanent marking are not installed within the available window, temporary markings should be required at the expense of the contractor.

■ Since the Standard Specifications prohibit painted temporary markings on the final lift of pavement, it may be appropriate to include a contract item for temporary markings for lifts other than the final lift, but not for the final lift. This will minimize the cost of the temporary markings item, and encourage the contractor to schedule permanent markings on the final lift in a timely manner.

g. No Existing Markings. When the existing road, prior to construction, has no centerline/passing zone markings, then temporary markings are not required prior to completion of the work, except if the construction is nearly complete (including one or more lifts of pavement materials), and has upgraded the geometrics and increased prevailing speeds, temporary markings shall be required in accordance with c. above.

h. One-Lane Paving. During construction when only one lane of a two-lane road is being paved, with the second lane paved the following day (as is permitted by the FP depending on lift thicknesses), the paving shall be offset so as not to obscure the existing markings, or temporary markings shall be installed on the one lane mat prior to opening it to traffic. In addition a symbolic or worded uneven lanes sign should be used in this situation.

I. Special Pavement Markings. The need for temporary school zone, railroad, cross walk, stop line, and other special pavement markings shall be evaluated on a case by case basis during the design process. Markings deemed warranted shall be included in the contract. This evaluation shall consider pedestrian traffic, limited sight distance and other potential hazards in addition to traffic volume and duration of construction.

J. DETOURS. PAVED TEMPORARY ROADS AND DETOURS WHICH ARE TO CARRY OTHER THAN LOW VOLUME TRAFFIC, OR ARE TO BE USED IN EXCESS OF TWO WEEKS SHALL RECEIVE STANDARD MARKINGS IN ACCORDANCE WITH MUTCD SECTIONS 3A AND 3B. WHEN TWO-WAY TRAFFIC IS DETOURED ONTO WHAT WOULD ORDINARILY BE A ONE-WAY ROAD, OR WHAT MAY APPEAR TO BE A ONE-WAY ROAD, SIGNING SHALL BE SUPPLEMENTED WITH W 6-3 "TWO-WAY TRAFFIC" SIGNS AT MAXIMUM ONE-KILOMETER INTERVALS.

K. STATE STANDARDS. IT IS NOT THE INTENTION OF FLH TO APPLY TEMPORARY MARKINGS STANDARDS TO ITS PROJECTS WHICH ARE LESS THAN THOSE APPLIED ON EQUIVALENT STATE HIGHWAY PROJECTS. DESIGNERS SHOULD BE COGNIZANT OF PREVAILING STATE STANDARDS AND MAKE UPWARD (BUT NOT DOWNWARD) ADJUSTMENTS TO FLH REQUIREMENTS WHENEVER APPROPRIATE.

l. Contract Provisions. It is important to structure contracts such that major overruns and unnecessary Government liability for short-term markings will not occur if the contractor elects to perform the paving and marking differently than the designer assumed. The following are general guidelines which must be reevaluated on a case-by-case basis.

- There should be sufficient quantities of short term markings to accommodate each lift of paving materials anticipated during construction.

- The contractor should be given the option of furnishing painted markings, reflective tape or temporary raised pavement markers. The bid item should include removal when required. Generally, painted short-term markings are cheapest and are appropriate immediately behind the paving operation on intermediate lifts. The temporary raised pavement markers are more practical on final lifts since they are easily removable prior to installing permanent markings, and are usually cheaper than reflective tape on roads with extensive no-passing zones. Where aesthetics has a high premium it may be appropriate to prohibit temporary painted markings on the final lift.

- The Government should not be obligated to pay for two systems on the same lift. If the time limit short-term (interim) markings expires due to poor scheduling, and the contractor has to install short-term (standard) markings, then the upgrade should be at the contractor's expense.

- For large projects, it is intended that the time limitations on short-term (interim) markings will force the contractor to complete manageable sections of the project through permanent striping, rather than have the entire project partially complete for an unacceptably long period of time.

4. Channelizing Devices. The preferred channelizing device for any application involving both day and night usage is the drum. If clearance or width problems preclude the use of drums, other devices such as vertical panels, barricades or tubular markers may be substituted. All devices should meet current crashworthiness standards.

The TCP should address, and contain standards as appropriate, defining the expected condition of the traveled way, and needs of public traffic through the duration of the project. Specific situations which should be addressed, through the use of appropriate signing and channelizing devices as appropriate, in each TCP include the following:

a. **Delineating Isolated Hazards**, e.g. partially complete guardrail, catch basins or major dropoffs.

b. **Protecting Workers** by separating traffic from active short term work site.

c. **Separating Opposing Lanes** of traffic in confined or detour situations.

d. **Tapers and Transitions** which move traffic from one lane to another, on or off a detour or facilitate a merge, lane narrowing, or one-lane flagging situation.

e. **Delineating Continuous Hazards**, e.g minor shoulder dropoffs.

f. **Delineating the Traveled Way** through a work zone, when no specific hazards are present. This use is often appropriate for low volume roads where no detour or temporary pavement surface is provided; and traffic must be routed through the work zone. Once the permanent channelizing cues, such as delineators and pavement markings, are removed, temporary delineation must be provided, especially for night time traffic.

The maximum spacing for channelizing devices is defined in meters as related to the prevailing speed (S) in kilometers per hour. For application **a.** and **b.**, above typical spacing is 0.2S. For **c.** and **d.** spacing is 0.2S to 0.4S depending on severity of risk factors. For **e.** and **f.** maximum spacing is 0.4S to 0.8S depending on severity of risk factors and visibility, i.e. for a long straight tangent where even at 0.8S, several devices would be visible, the higher spacing could be used.

Depending on traffic volume, speed, duration of condition, geometrics and related risk assessment factors, situations **a.** through **d.** above, may warrant the use of temporary concrete barrier. In high risk situations channelizing devices should not be used alone, when a positive barrier is warranted.

I. Traffic Signals. As most FLHP work is in rural areas, there is seldom a need for signalized intersections or advanced traffic control systems such as ramp monitoring on controlled access facilities. However, temporary signals are an effective tool for managing traffic where one-lane operations are required for bridge rehabilitation or similar work. Gather all available information or traffic volumes, turning movements, and accident data (e.g., frequency, location, type, speeds).

The design of traffic signal devices and warrants for their use are covered in Part IV of the *MUTCD*. Consult additional reference sources when designing signalized intersections and other traffic control systems not covered by the *MUTCD*. The *Traffic Control Devices Handbook* provides the fundamental procedures for proper analysis and design of traffic control systems as well as the Transportation Research Board's Special Report 209, *Highway Capacity Manual*.

Traffic control signals are devices that control vehicular and pedestrian traffic by assigning the right-of-way to various movements for certain pre-timed or traffic-actuated intervals of time. They are one of the key elements in the function of many urban streets and of some rural intersections. Thus the planned signal system for a facility should be integrated with the design to achieve optimum safety, operation, capacity, and efficiency. Careful consideration should be given in plan development to intersection and access locations, horizontal and vertical curvature, pedestrian requirements, and geometric schematics to ensure the best possible signal progression, speeds, and phasing. In addition to initial installation, possible future need should also be evaluated.

Owner agencies or State highway agencies are usually a good source for design assistance, particularly in the area of equipment compatibility and electrical design.

8.5 (RESERVED)

8.6 (RESERVED)

8.7 DIVISION PROCEDURES

Reserved for Federal Lands Highway Division office use in supplementing the policy and guidelines set forth in this chapter with appropriate Division procedures and direction.

CFL Procedures

EFL Procedures

WFL Procedures
http://www.wfl.fhwa.dot.gov/design/manual/ch08/

LIST OF EXHIBITS

Exhibit

GENERAL ACCIDENT PATTERNS		
Accident Pattern	Probable Cause	Safety Enhancement
Run-off roadway	Slippery pavement	Improve skid resistance Provide adequate drainage Groove existing pavement
	Roadway design inadequate for traffic conditions	Widen lane/shoulders Relocate islands Provide proper superelevation Install/improve traffic barriers Improve alignment/grade Flatten slopes/ditches Provide escape ramp
	Poor delineation	Improve/install pavement markings Install roadside delineators Install advance warning signs
	Poor visibility	Improve roadway lighting Increase sign size
	Inadequate shoulder	Upgrade roadway shoulders
	Improper channelization	Improve channelization
Bridges	Alignment	Realign bridge/roadway Install advance warning signs Improve delineation/markings
	Narrow roadway	Widen structure Improve delineation/markings Install signing/signals
	Visibility	Remove obstruction Install advance warning signs Improve delineation and markings
	Vertical clearance	Rebuild structure/adjust roadway grade Install advance warning signs Improve delineation and markings Provide height restriction/warning device
	Slippery surface (Wet/icy)	Resurface deck Improve skid resistance Provide adequate drainage Provide special signing
	Rough surface	Resurface deck Rehabilitate joints Regrade approaches
	Inadequate barrier system	Upgrade bridge rail Upgrade approach rail/terminals Upgrade bridge - approach rail connections Remove hazardous curb Improve delineation and markings

EXHIBIT 8.1
General Accident Patterns

GENERAL ACCIDENT PATTERNS		
Accident Pattern	Probable Cause	Safety Enhancement
Overturn	Roadside features	Flatten slopes and ditches Relocate drainage facilities Extend culverts Provide traversable culvert end treatments Install/improve traffic barriers
	Inadequate shoulder	Widen lane/shoulder Upgrade shoulder surface Remove curbing/obstructions
	Pavement feature	Eliminate edge drop-off Improve superelevation/crown
Parked vehicles	Inadequate road design	Widen lanes/shoulders
Fixed object	Obstructions in or too close to roadway	Remove/relocate obstacles Make drainage headwalls flush with side slope Install breakaway features to light poles, signposts, etc... Protect objects with guardrail Delineation/reflectorize safety hardware
	Inadequate lighting	Improve roadway lighting
	Inadequate pavement markings, signs, delineators, and guardrail	Install reflectorized pavement lines/raised markers Install reflectorized paint and/or reflectors on the obstruction Add special signing Upgrade barrier system
	inadequate road design	Improve alignment/grade Provide proper superelevation Install warning signs/delineators Provide wider lanes
	Slippery surface	Improve skid resistance Provide adequate drainage Groove existing pavement
Sideswipe or head-on	Inadequate road design	Provide wider lanes Improve alignment/grade Provide passing lanes Provide roadside delineators Sign and mark unsafe passing areas
	Inadequate shoulders	Improve shoulders
	Excessive vehicle speed	Install median devices
	Inadequate pavement markings	Install/improve centerline, lane lines, and edge lines Install reflectorized markers
	Inadequate channelization	Install acceleration and deceleration lanes Improve/install channelization Provide turning bays
Sideswipe or head-on (Continued)	Inadequate signing	Provide advance direction and warning signs Add illuminated name signs

EXHIBIT 8.1
General Accident Patterns

GENERAL ACCIDENT PATTERNS		
Accident Pattern	Probable Cause	Safety Enhancement
Access-related	Left-turning vehicles	Install median devices Install two-way left-turn lanes
	Improperly located driveway	Move driveway to side street Install curbing to define driveway location Consolidate adjacent driveways
	Right-turning vehicles	Provide right-turn lanes Increase width of driveways Widen through lanes Increase curb radii
	Large volume of through traffic	Move driveway to side street Construct a local service road
	Large volume of driveway traffic	Signalize driveway Provide acceleration and deceleration lanes Channelize driveway
	Restricted sight	Remove obstructions
	Inadequate lighting	Improve street lighting
Intersection (signalized/ unsignalized) left turn, head-on, right angle, rear end	Large volume of left/right turns	Widen road Channelize intersection Install STOP signs Provide signal Increase curb radii
	Restricted sight distance	Remove sight obstruction Provide adequate channelization Provide left/right turn lanes Install warning signs Install STOP signs Install signal Install advance markings to supplement signs Install STOP bars
	Slippery surface	Improve skid resistance Provide adequate drainage Groove pavement
	Large numbers of turning vehicles	Provide left- or right-turn lanes Increase curb radii Install signal
	Inadequate lighting	Improve roadway lighting
	Lack of adequate gaps	Provide signal Provide STOP signs

EXHIBIT 8.1
General Accident Patterns

GENERAL ACCIDENT PATTERNS		
Accident Pattern	Probable Cause	Safety Enhancement
Intersection (signalized/ unsignalized) left turn, head-on, right angle, rear end (Continued)	Crossing pedestrians	Install/improve signing or marking of pedestrian crosswalks Install signal
	Large total intersection volume	Install signal Add traffic lane
	Excessive speed on approaches	Install rumble strips
	Inadequate advance warning signs	Improve warning devices Install advance warning signs
	Inadequate traffic control devices	Upgrade traffic control devices
	Poor visibility of signals	Install/improve advance warning signs Install overhead signals Install 300 mm signal lenses Install visors/back plates Relocate signals Remove sight obstructions Add illumination/reflectorized name signs
	Unwarranted signals	Remove signals
	Inadequate signal timing	Upgrade signal system timing/phasing
Nighttime	Poor visibility or lighting	Install/improve street lighting Install/improve delineation/markings Install/improve warning signs
	Poor sign quality	Upgrade signing Provide illuminated/reflectorized signs
	Inadequate channelization or delineation	Install pavement markings Improve channelization/delineation
Wet pavement	Slippery pavement	Improve skid resistance Groove existing pavement
	Inadequate drainage	Provide adequate drainage
	Inadequate pavement markings	Install raised/reflectorized pavement markings
Pedestrian/bicycle	Limited sight distance	Remove sight obstructions Install/improve pedestrian crossing signs and markings
	Inadequate protection	Add pedestrian refuge islands
	Inadequate signals/signs	Install/upgrade signals/signs
	Mid-block crossings	Install warning signs/markings

EXHIBIT 8.1
General Accident Patterns

GENERAL ACCIDENT PATTERNS		
Accident Pattern	Probable Cause	Safety Enhancement
Pedestrian/bicycle (Continued)	Inadequate pavement markings	Supplement markings with signing Upgrade pavement markings
	Lack of crossing opportunity	Install traffic/pedestrian signals Install pedestrian crosswalk and signs
	Inadequate lighting	Improve lighting
	Excessive vehicle speed	Install proper warning signs
	Pedestrians/bicycles on roadway	Install sidewalks Install bike lanes/path Eliminate roadside obstructions Install curb ramps
	Long distance to nearest crosswalk	Install pedestrian crosswalk Install pedestrian actuated signals
Railroad crossings	Restricted sight distance	Remove sight obstructions Reduce grade Install active warning devices Install advance warning signs
	Poor visibility	Improve roadway lighting Increase size of signs Install advance markings to supplement signs
	Inadequate pavement markings	Install STOP bars Install/improve pavement markings
	Rough crossing surface	Improve crossing surface
	Sharp crossing angle	Rebuild crossing with proper angle

EXHIBIT 8.1
General Accident Patterns

ROADSIDE HAZARD REVIEW

State: **Montana** Prepared by: **Paul Schneider**
County: **Flathead** Date: **May 19, 1996**

National Forest/Park: **Glacier National Park**

Highway Route: **U.S. Route 2** Limits: **193+116 to 202+128** Length: **9.0 km**
General Location: **Beginning 1 km south of Camas and extending north to top of graveyard hill at Essex.**

Item	Hazard Location		Description of Hazard	Action	Cost	Remarks
	Station	Lt/Rt (m)				
1	193+438	6.0 Rt	100 x 100 wood sign post	Yes	$ 90	Relocate to backslope
2	194+082	4.9 Rt	100 x 100 wood sign post	Yes	$ 90	Relocate to backslope
3	194+243	5.5 Lt	Concrete culvert headwall	Yes	$ 500	Replace existing culvert
4	194+323	4.9 Rt	Concrete culvert headwall	Yes	$ 600	Replace existing culvert
5	194+564	3.7 Lt	Mailbox in no-passing zone	Widen	$1000	Provide mailbox turnout
6	194+886	4.3 Rt	Two 100 x 150 wood sign posts (not drilled)	Yes	$ 50	Drill posts
7	195+530	4.9 Lt	Abrupt culvert ends	Yes	$ 250	Lengthen culvert - metal end sections
8	196+013	4.6 Lt	Mailbox - good sight distance	No	-	Tight right-of-way
9	196+013	5.5 Lt	Abrupt approach road culvert	Yes	$ 600	Extend approach culvert and flatten slope to 1:10
10	196+174 to 196+656	6.7 Rt	Steep fill slope	None	-	Not cost effective guardrail
11	197+300	6.0 Lt	Concrete culvert headwall	Yes	$ 500	Replace and extend
12	198+105	5.5 Rt	Abrupt approach road culvert	Yes	$ 600	Extend culvert and flatten slope to 1:10
13	200+680	4.3 Rt	Concrete culvert headwall	Yes	$ 500	Replace existing culvert
14	201+645	3.7 Lt	Mailboxes (4)	Widen	$2500	Provide mailbox turnout

EXHIBIT 8.2
Sample of a Roadside Hazard Review

Design and Construction Notes for Aesthetic Barriers

Steel-backed Timber Guardrail

1. The steel-backed timber guardrail has been crash tested and meets the requirements of NCHRP Report 230. The blocked-out option, type A, is approved for design speeds of 100 km/h and less. The option without the block-out, type B, is approved for use for design speeds of 80 km/h and less. Unless there are objections, the preferred installation is the type A.

2. Numerous designs for the steel-backed timber guardrail and its terminals have been reviewed and tested during the development of this system. Federal Lands Highway Standard Drawings for berms, turn-down terminals, and back-slope anchored terminals reflect the best compromise of safety, aesthetics, and ease of construction. Due to the possible effect on the crash worthiness of the guardrail, any modifications to Federal Lands Highway Standards for the steel-backed timber guardrail must be approved by the Federal Lands Highway Office.

3. The grading in front and directly behind the guardrail and terminals must be at a slope of 1:10 or flatter for the guardrail to be effective.

4. The maximum dynamic deflection of the steel-backed timber guardrail is approximately 450 mm for design speeds of 80 km/h and less. The dynamic deflection is approximately 750 mm for design speeds between 80 and 100 km/h. The back of the rail must be set at least these distances from a fixed object, such as a tree or bridge pier.

5. Field modifications to the structural steel, such as enlargement of the bolt slots, are not permitted, due to the effect on the crash worthiness of the system.

6. There should be at least 600 mm between the back of the guardrail posts and the top of a 1:2 slope or steeper. If this is unobtainable, the length of the guardrail posts should be increased to 2.4 m. The increase strength of the 2.4 m posts without the 600 mm soil backup is marginal and should only be used for short segments.

7. No steel-backed timber guardrail terminals have been crash tested. The Federal Lands Highway Office has standard drawings designed specifically for the steel-backed timber guardrail for a berm, a back-slope anchored terminal, and a flared anchored terminal (turn-down), and may be used:

    a. Where there is adequate room, the preferred terminal is the flared anchored terminal (FAT) with an earth berm. The terminal section should be located outside the clear zone, but if this is impractical it should be flared as far from the roadway as possible. The earth berm should be oriented approximately parallel to the roadway. It is intended that each berm will be stacked to fit its particular location. For safety, aesthetics, and maintenance considerations, it is desirable to flatten the slopes of the berm as much as possible. A 1:3 sideslope on the berm facing the roadway is considered minimally acceptable. It is also desirable to increase the height of the berm, but the 1:20 approach slope must be maintained.

EXHIBIT 8.3
Design and Construction Notes for Aesthetic Barriers

Steel-backed Timber Guardrail (Continued)

b. Where there is a back-slope to tie to, the preferred terminal is the back-slope anchored terminal (BAT). Crash tests with similar designs with W-beam guardrail have established a weakness in this design where the guardrail crosses a ditch. Due to this weakness, ditches under this terminal should be as flat as possible. It is recommended that the sideslopes of the ditches be no steeper than 1:10.

c. Where it is not possible to construct an earth berm or tie to a backslope, the guardrail may be terminated using the FAT without a berm. Crash tests on similar turn-down designs have demonstrated the potential for this type terminal to launch a vehicle or produce a rollover. However, this terminal is superior to leaving the exposed guardrail end that could snag or even penetrate a vehicle. The widened shoulder area and guardrail flare aids is providing stability for a vehicle riding up on the terminal.

Stone Masonry Guardwall

1. The stone masonry guardwall has been crash tested and meets the requirements of NCHRP Report 230. This rough-faced barrier system is approved for design speed of 100 km/h or less. A smooth-faced wall with smaller projections and shallower raked joints and beds is also approved.

2. The crash tested rough stone masonry guardwall used specifications that defined the maximum projections up to 38 mm beyond the neat line, 50 mm deep raked joints, and beds 50-75 mm thick. Based on aesthetics and available stone, specifications for the guardwall may be revised to specify any smoother stone face, such as class A or B masonry. Stone faces with critical dimensions greater than those listed above are not considered crash worthy.

3. Numerous designs for the stone masonry guardwall and its terminals have been reviewed and tested during the development of this system. One of the critical dimensions is the 500 mm between the ground line and the top of the corewall. Federal Lands Highway Standard Drawings for berms, turn-down terminals, and back-slope anchored terminals reflect the best compromise of safety, aesthetics, and ease of construction. Prior designs are not to be used. Due to the possible effect on the crash worthiness of the guardwall, any modifications to Federal Lands Highway Standards for the stone masonry guardwall must be approved by the Federal Lands Highway Office.

4. The grading in front of the guardwall and terminals must be at a slope of 1:10 or flatter for the guardwall to be effective.

5. The maximum dynamic deflection of the stone masonry guardwall is 0 m for design speeds of 100 km/h or less.

6. During construction, care should be taken to avoid large rock projections oriented toward oncoming traffic. Such projections have a tendency to snag a vehicle resulting in greater vehicle and occupant injury. The recommended orientation for the projections is away from oncoming traffic, so that the vehicle can ride over the projections.

Stone Masonry Guardwall (Continued)

7. No stone masonry guardwall terminals have been crash tested. The Federal Lands Highway Office has standard drawings designed specifically for the stone masonry guardwall for a berm Buried terminal (BT), a back-slope anchored terminal (BAT), and a stand alone terminal (SAT) (turn-down), and may be used:

   a. Where there is adequate room, the preferred terminal is the buried terminal (BT) with an earth berm. The terminal section should be located outside the clear zone, but if this is impractical it should be flared as far from the roadway as possible. The earth berm should be oriented approximately parallel to the roadway. It is intended that each berm will be stacked to fit its particular location. For safety, aesthetics, and maintenance considerations, it is desirable to flatten the slopes of the berm as much as possible. A 1:3 sideslope on the berm facing the roadway is considered minimally acceptable. It is also desirable to increase the height of the berm, but the 1:20 approach slope must be maintained.

   b. Where there is a back-slope to tie to, the preferred terminal is the back-slope anchored terminal (BAT). Special consideration will be needed to maintain drainage, because this terminal will not accommodate a drainage ditch.

   c. Where it is not possible to construct an earth berm or tie to a backslope, the guardrail may be terminated using the SAT. Crash tests on similar turn-down designs have demonstrated the potential for this type terminal to launch a vehicle or produce a rollover. However, this terminal is superior to leaving the exposed guardrail end that could snag or even penetrate a vehicle. The widened shoulder area and guardrail flare aids is providing stability for a vehicle riding up on the terminal.

Precast Concrete Guardwall

1. The precast concrete guardwall has been crash tested and meets the requirements of NCHRP Report 230. This artificial stone system is approved for design speed of 100 km/h or less.

2. Based on the crash tests for the stone masonry guardwall the precast concrete guardwall may use specifications that define the maximum projections up to 38 mm beyond the neat line, 50 mm deep raked joints, and beds 50-75 mm thick. Based on aesthetics, specifications for the guardwall may be revised to specify any smoother artificial stone face. Artificial stone faces with critical dimensions greater than those listed above are not considered crash worthy.

3. Numerous designs for the precast concrete guardwall and terminal sections have been reviewed and tested during the development of this system. Federal Lands Highway Standard Drawings for berms, turn-down terminals, and back-slope anchored terminals reflect the best compromise of safety, aesthetics, and ease of construction. Due to the possible effect on the crash worthiness of the guardwall, any modifications to Federal Lands Highway Standards for the stone masonry guardwall must be approved by the Federal Lands Highway Office.

Precast Concrete Guardwall (Continued)

4. The grading in front of the guardwall and terminals must be at a slope of 1:10 or flatter for the guardwall to be effective.

5. The maximum dynamic deflection of the stone masonry guardwall is 0 m for design speeds of 100 km/h or less.

6. During construction, care should be taken to avoid large rock projections oriented toward oncoming traffic. Such projections have a tendency to snag a vehicle resulting in greater vehicle and occupant injury. The recommended orientation for the projections is away from oncoming traffic, so that the vehicle can ride over the projections.

7. The precast concrete guardwall was crash tested 3.66 m behind a 88.9 mm mountable curb. Since the 3.66 m is considered to be the critical offset distance, the guardwall is approved for use with any 90 mm mountable curb at any offset.

8. The precast concrete guardwall can be used as a median barrier as long as both sides of the guardwall have a vertical face.

9. No precast concrete guardwall terminals have been crash tested. The Federal Lands Highway Office has standard drawings designed specifically for the precast concrete guardwall and may use drawings designed for the stone masonry guardwall for a berm Buried terminal (BT), a back-slope anchored terminal (BAT), and a stand alone terminal (SAT) (turn-down), and may be used:

   a. The precast concrete guardwall terminal sections were designed specifically for use with an earth berm in a median. The steep 1:4.5 tapers on these terminal sections necessitate the use of a 600 mm earth berm. The sideslopes on the earth berm should be 1:4 or flatter and the approach slope should be 1:20 or flatter. The approach slope for opposing traffic may be steepened to a maximum of 1:6 if there is inadequate room for the 1:20 slope. However, in no case should the 1:20 approach slope be steepened.

   b. For roadside applications where there is adequate room, the preferred terminal is the buried terminal (BT) with an earth berm. Due to the steep 1:4.5 top tapers, the earth berm must have a 600 mm earth berm specified instead of the standard 450 mm berm. The terminal section should be located outside the clear zone, but if this is impractical it should be flared as far from the roadway as possible. The earth berm should be oriented approximately parallel to the roadway. It is intended that each berm will be stacked to fit its particular location. For safety, aesthetics, and maintenance considerations, it is desirable to flatten the slopes of the berm as much as possible. A 1:3 sideslope on the berm facing the roadway is considered minimally acceptable. It is also desirable to increase the height of the berm, but the 1:20 approach slope must be maintained.

   c. Where there is a back-slope to tie to, the preferred terminal is the back-slope anchored terminal (BAT). Special consideration will be needed to maintain drainage, because this terminal will not accommodate a drainage ditch.

Precast Concrete Guardwall (Continued)

d. Where it is not possible to construct an earth berm or tie to a backslope, the guardwall may be terminated using the SAT (turned-down) without an earth berm. Crash tests on similar turn-down designs have demonstrated the potential for this type terminal to launch a vehicle or produce a rollover. However, this terminal is superior to leaving the exposed guardrail end that could snag or even penetrate a vehicle. The widened shoulder area and guardrail flare aids is providing stability for a vehicle riding up on the terminal. Precast concrete terminals may only be used without an earth berm if they are located outside the clear zone.